BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: Proposal for a Spent-Stage Impact Experiment - Case 340

DATE: March 14, 1969

FROM: M. T. Yates

MEMORANDUM FOR FILE

I. INTRODUCTION

The purpose of the proposed "Spent-Stage Impact Experiment" is to support the ALSEP Passive Seismic Experiment by providing seismic events on the moon at known positions and times. This would be accomplished by altering the trajectory of each spent S-IVB stage so that it impacts the moon within a few hundred kilometers of a previously emplaced seismometer.

The potential scientific data from the experiment will be the four known coordinates of the event (3 spatial, 1 time) and the known energy of the impacting stage ($\sim 5.4 \times 10^{10}$ J). This will allow immediate determination of travel times and seismic velocities, possible detection of a lunar mantle, and an estimate of the coefficient of attenuation of the lunar interior.

II. RATIONALE

The Passive Seismic Experiment (PSE), a part of the Apollo Lunar Surface Experiments Package, is expected to provide a majority of the data necessary to answer questions on the origin, present physical state, and dynamic behavior of the moon. Unfortunately, the quality of the returned data depends to some extent on the frequency and magnitude of lunar seismic events. An unusually high seismic noise level would hamper the identification of separate events while a dirth of moonquakes could result in an inadequate number of events for unambiguous results during the lifetime of the instrument. While nothing can be done to reduce the seismic noise level at a site without equally reducing the desired signals, it is unlikely that this will be a problem. An insufficiency of detectable seismic events, however, is more probable[1,2] due either to negative velocity gradients, high attenuation, or a lack of tectonic activity in the moon. Also the full utility of the PSE will not be realized until the data is sufficiently redundant to accurately locate the seismic events in time and space. Normally this would require four seismometer stations operating simultaneously. Using present ALSEP reliability numbers[3] and assuming

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launches on 3 month centers, the probability of receiving data simultaneously from 4 ALSEP PSE's for at least a three month period is about 0.67.

The proposed Spent-Stage Impact Experiment would guarantee a number of seismic events of known location, time and (approximate) magnitude. This would assure a useful data return independent of the seismicity of the moon and, more important, provide the necessary source coordinates so that the data from one station could be unambiguously reduced to provide initial points on a lunar seismic velocity-depth profile. These data should help answer such questions as:

1. "Has the moon undergone chemical differentiation?"

2. "Is there a distinct crust-mantle boundary?"

3. "Is the temperature gradient high enough to cause high seismic attenuation or a negative velocity gradient?"

4. "Are the lunar seismic velocities comparable to those within the Earth?"

From previous calculations,[4] the author has determined that the equivalent earthquake magnitude (based on surface wave amplitudes) of an S-IVB impact is expected to range from 0.5 to 2.2 depending on the cohesiveness of, and thus energy coupling to, the lunar surface and on how well the impact can be represented by relations derived from explosions. On earth this would give a maximum detectable range of 120 to 500 km for a seismometer with 1 nanometer sensitivity. In a recent calculation[5] based on extrapolation of seismic amplitudes resulting from small projectiles impacting epoxy-bonded sand, a minimum detectable range of 150 to 680 km is predicted for an S-IVB impact depending on the assumed lunar attenuation. Thus, two independent methods of assessing the maximum range give answers in satisfactory agreement.

III. FEASIBILITY

The questions pertinent to the feasibility of the proposed experiment are:

a) Can S-IVB lunar impact be achieved operationally?

b) What mission constraints or guidelines need to be waived?

c) What tracking and timing accuracy can be assured, and is this sufficient for the scientific requirements?

A. Implementation

The answer to the first question is yes. The present mode of S-IVB disposal (implemented on the Apollo 8 mission) is to propulsively dump the cryogenics (LOX and LH_2) so that the resultant ΔV is sufficient to alter the trajectory from free return to earth-escape. The required ΔV depends on the orientation of the S-IVB and the time of the dump but is of the order of 30 m/sec. Present fuel margins are sufficient to supply ΔV capability for such a trajectory.

A further consideration is the possibility of getting too large an impulse from the dump. The fuel residuals will be poorly known at the time of the dump, and control of the dumping process is certainly less precise than, say, controlling a burn. The LOX and LH_2 dump can be commanded on and off and either a propulsive or non propulsive mode can be chosen. In addition, the Auxiliary Propulsion System (APS) normally used for attitude control can be burned in a translational mode. The cryogenics must be dumped, one way or the other, fairly soon after transposition and docking to prevent pressure buildup and tank rupture. The maximum allowable ΔV for an impact trajectory is around 20 to 25 m/sec for a nominal case, but is a sensitive function of the orientation of the S-IVB.[(6)] S-IVB orientation is in turn somewhat constrained by antenna pointing requirements and gimbal travel but should allow ΔV's as high as 50 m/sec to be tolerated. This margin along with the available dumping commands should provide sufficient flexibility to insure an S-IVB lunar impact over a wide range of initial conditions.

B. Mission Constraints

The present requirements for S-IVB disposal are stated in the Apollo Flight Mission Assignments document[7] in terms of three objectives, which are (in order of decreasing priority):

1. Reduce the probability of S-IVB/spacecraft recontact.

2. Reduce the probability of earth impact.

3. Reduce the probability of lunar impact.

Of these three, the first two are obvious safety considerations while the third is aimed at reducing contamination of the lunar surface and atmosphere. In order to justify waiving this third objective, it must be shown that the first two objectives will not be compromised and that the lunar contamination due to S-IVB impact is relatively insignificant.

The highest priority objective is to avoid S-IVB/spacecraft recontact. A definitive way to show that this objective is satisfied during the S-IVB course change would be to calculate the S-IVB/spacecraft relative distance for various initial conditions. However, it can be argued quite generally that since a negative ΔV is required for an impact (or slingshot) trajectory, the relative separation of the S-IVB and CSM will always be a monotonically increasing function of time.* This argument is developed in detail and substantiated by calculations of the relative separation as a function of range in Reference 6.

The second priority objective of the S-IVB disposal maneuver is to avoid earth impact. For this objective earth impact is considered to be any elliptical orbit since solar and lunar perturbations may cause such an orbit to decay and eventually impact the earth. The present S-IVB maneuver to a slingshot trajectory was instituted to insure that a hyperbolic (heliocentric) orbit would be achieved. A lunar impact trajectory would also, of course, guarantee no earth impact. The uncertainty in the possible ΔV would need to be allowed for by orienting the S-IVB so that in the worst case the spent stage would not hit the elliptic orbit corridor (perilune $\gtrsim$ 6 lunar radii, east limb, > 1 radius, west limb) rather than the impact corridor.

Contamination of the lunar atmosphere caused by an impacting S-IVB will come primarily from the volatiles (residual fuels) remaining in the vehicle at time of impact. Although fuel residuals may be of the order of 400 lbs after venting, this represents less than 10% of the amount of LM ascent and descent exhaust gases that actually impinge upon the lunar surface and less than 2% of the total LM exhausts. The lifetime of the gases released on or near the lunar surface should be a few days, after which time the pressure will have dropped to its equilibrium level ($<10^{-11}$ torr). Thus, the total contamination of the lunar atmosphere is not significantly increased by impacting the spent S-IVB.

C. <u>Tracking and Timing</u>

The ability to actively track the present S-IVB configuration with its attached instrument unit (IU) is limited

*The component of the ΔV along the velocity vector is negative. The out of plane component also increases the relative separation.

by the active lifetime of these stages (spec. lifetime 7 hours). In the Apollo 8 mission the S-IVB began tumbling (guidance system failure) between 5 and 6 hours into the flight, but its transmitters remained functioning for about 12 hours.

In order to maximize the accuracy of the impact point determination, the S-IVB will need to be tracked during the entire translunar trajectory, that is, for about 70 hours after launch. In order not to require the life of the entire IU to be upgraded, this should probably be implemented with a separate self-powered S-Band transponder.* Early loss of attitude control and mid-course correction capability should not have serious impact on the experiment since the required accuracy in hitting a pre-selected target is relatively low (∿50 km) and does not directly affect the accuracy of the result.

However, how closely the actual impact point can be determined will be directly reflected in the accuracy of the seismic velocities derived from the resultant data. For distances from impact point to seismometer of around 100 km, an impact point accuracy of 1 km would be optimum and 5 km would be acceptable.

It is doubtful whether present tracking techniques could provide the impact point to within 1 km. Continuous tracking of Ranger VII gave an impact point 2.5 km displaced from that determined from the transmitted photos. However, 5 km accuracy should be possible, and this number may be significantly reduced by using an improved ephemeris to analyze the tracking data.[8]

Timing of the impact should be at least as accurate as the optimum targeting accuracy, which for Earth-typical seismic velocities would imply impact time to within ±0.1 sec. Although ±0.5 sec would be acceptable, it should not be difficult to achieve ±0.1 sec accuracy for transmitter termination at impact. Ranger VII impact timing was accurate to ±0.02 sec (limited by calibration to GMT) and precise to 0.001/sec.

Since the impact point does not need to be known in real time, it may be possible to provide visual backup of the MSFN tracking. If the impact could be targeted with reasonable certainty into an area to be overflown by the command module and covered by Orbiter high resolution (1 m) photography, post impact photography from the command module of the anticipated impact area could reveal the new crater. Since the expected crater diameter would be ∿33 m, the 250 mm Hasselblad lens would probably be necessary to insure sufficient resolution.[9]

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*Alternatively, an additional power supply could be provided for the existing S-Band transponder. A study of the tradeoffs pertinent to this problem is needed.

IV. SUMMARY

The proposed S-IVB impact experiment is feasible with small impact on the existing hardware configuration. An S-Band transponder with a lifetime of more than 70 hrs. is required for the S-IVB/IU. This may also satisfy the requirement for time of impact, otherwise an additional small (<1 watt) transmitter will be needed. Tracking coverage must be provided up to the time of impact. It may also be possible to provide photographic backup from the CSM for impact point determination. The Apollo Flight Mission Assignment document must be revised in order to allow lunar impact of the S-IVB. This will not compromise the spacecraft recontact or earth impact objectives nor significantly increase lunar contamination. The implementation of this experiment is required only for the G2 (second lunar landing) and subsequent. However, it would be highly desirable to attempt it, at least in part, on the F or G1 missions in order to verify tracking capability and the general feasibility of the experiment.

Summary of Specifications

	acceptable accuracy	optimum accuracy
Pre-Selected Target Point	100 km	50 km
Determination of Impact Point	5 km	1 km
Time of Impact	±0.5 sec	±0.1 sec

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The potential scientific data from the experiment will be the four known coordinates of the event (3 spatial, 1 time) and the known energy of the impacting stage. This will allow immediate determination of travel times and seismic velocities, possible detection of a lunar mantle, and an estimate of the coefficient of attenuation of the lunar interior.

Implementation of the experiment requires a long lived S-Band transponder for the S-IVB/IU for accurate impact determination. Present knowledge of the lunar ephemeris will allow acceptable (though not optimum) tracking accuracy.